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HIGH PRESSURE SPACE SUIT GLOVE

FINAL REPORT

January 2, 1972

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Prepared Under Contract No. NAS2-7009

By

SPACE-AGE CONTROL, INC.
Palmdale, California

For

Ames Research Center
National Aeronautics and Space Administration

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1.0 SUMMARY

1.1 Work began on the High Pressure Space Suit Glove development at Space-Age Control, Inc. on June 14, 1972.

1.2 Objectives of the contract were the development of a prototype full-pressure glove that would provide maximum dexterity, tactility, and stability at an operating pressure of 8 psid.

1.3 The six-month program encompassed the design/development, fabrication, and test in three phases.

Phase A - Detail design and configuration analysis.

Phase B - Fabrication and test of prototype segments.

Phase C. - Fabrication and test of one end item prototype glove.

1.4 The end item was shipped to NASA Ames Research Center on November 20, 1972.

2.0 INTRODUCTION

2.1 This report describes the effort for development, fabrication, and verification testing of a prototype High Pressure Space Suit Glove to support advanced space missions.

Pressure suit garment state-of-the-art has made considerable advancements in the development of highly articulate joint structures. Both hard and soft suits have attained acceptable designs of stable, continuous volume, low-torque joints. One area of pressure suit design that is noticeably lacking in advanced development is the glove. Due to the small size and close proximity of the fingers and thumb, none of the successful design elements that are employed in the torso/limb designs are readily adaptable to gloves.

This program has had as a goal, the development of a pressure glove that would provide comfort, low-torque flexibility and good neutral range at an operational pressure of 8 psi.

3.0 ACTIVITIES AND ACCOMPLISHMENTS

3.1 History of Development

The program was organized into the following sections in order that each section would compliment the others and to prevent duplication of effort.

.....Review of previous glove design efforts

.....Thumb anatomical review

.....Glove design areas

- .....Wrist
- .....Palm restraint
- .....Fingers
- .....Thumb

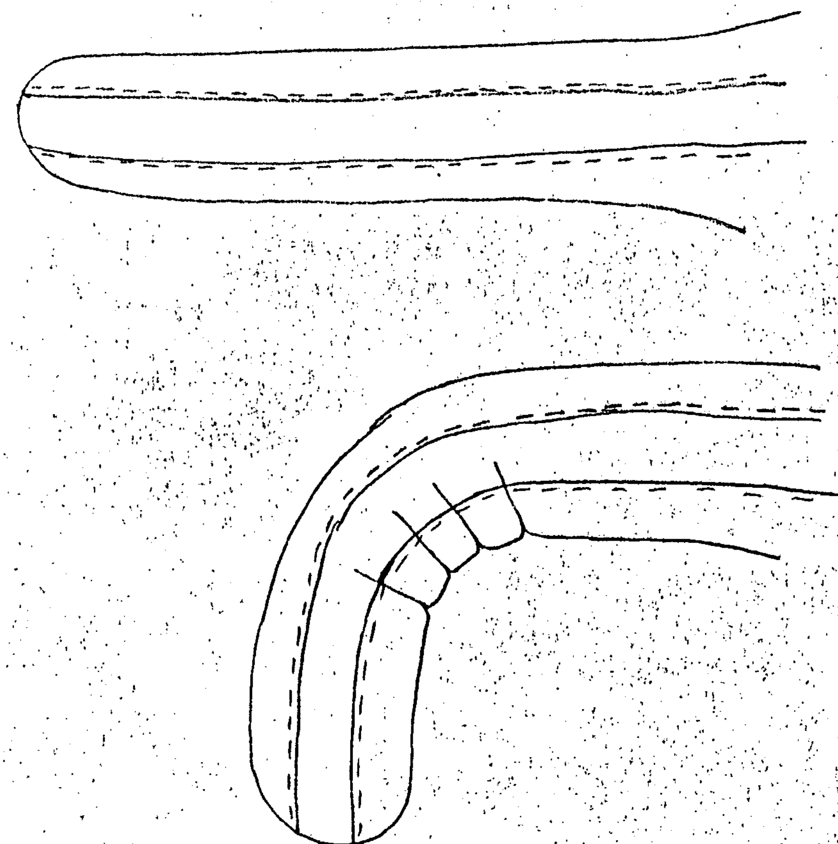
3.1.1 Glove Design Review

A review of various gloves that make up the historical inventory of flight hardware indicates that early versions simply evolved from what was known of glove patterns. Little or no regard to the engineering mechanics involved in pressurizing a glove was considered. This is evident in the gloves used with the partial pressure suits and even today with some of our full-pressure suits. Figure 1 shows a typical glove finger design that is in use today. If we visualize this cylinder (finger) in the pressurized mode we can readily see that the bending moment will be large (proportional to the internal pressure and to the third power of the radius). The volume does not remain constant and no stability can be attained. In addition to the force required to bend a simple cylinder, additional forces are incurred due to the two seams on each side.

When the finger flexes, the upper skin line extends or "grows" approximately 0.75 inches (large middle finger, max flex). In the above glove design, no provision is provided for dorsal growth. Later versions of this design incorporated "pleats" on the upper surface; however, this did not satisfy normal motion requirements as the pleat covered only 1/3 of the circumference and therefore did little to offset the dorsal growth and bending moment problem.

Later glove development included a dipped glove that eliminated the seams at fingers and thumb. This design did not allow sufficient growth along dorsal surface and did not control the roots of the convolute which allowed ballooning and therefore loss of effective design.

A significant advancement in glove design was the mini-convolute resulting from NASA program NAS2-6154. This design allowed more than the required dorsal growth, and convolute bending axis was 50% or more of the finger circumference. Finger mobility exhibited low



PRESSURE GLOVE FINGER

Figure 1

torque and good stability. Construction techniques are very costly and time consuming using the mini-convolutes and the seams formed by joining laminate material to the convolutes results in an undesirable stiffness. The seams present a problem of strength reliability at 8 psi (since they must be kept very narrow) and 5000 cycles at 8 psi will probably result in failure where the seams bend. A disappointing feature of the mini-convolute glove was the lack of thumb mobility. Because of the complexity of designing a pressure glove thumb, a separate review of the thumb is presented.

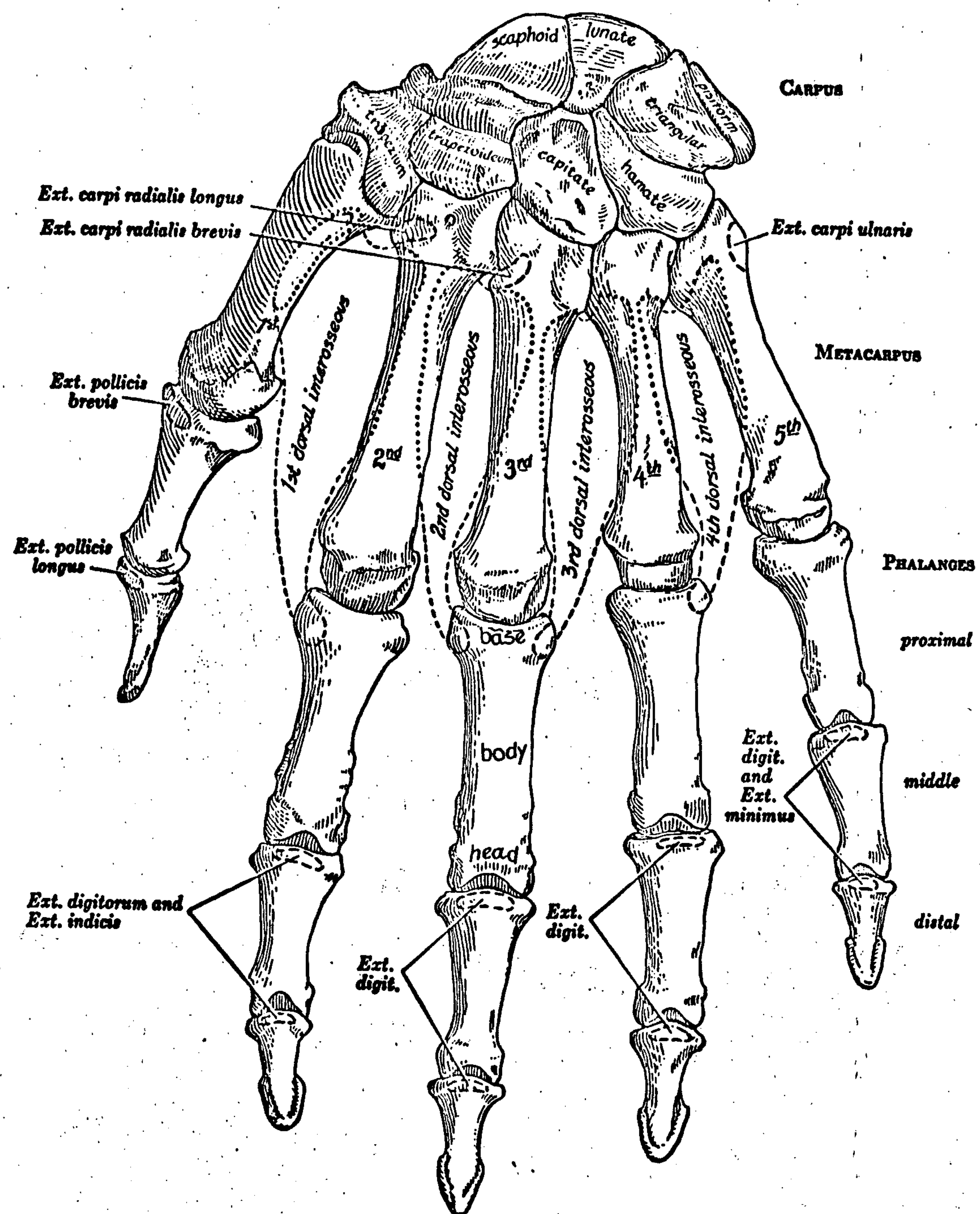
3.1.2 Thumb Anatomical Review

The problems of designing a highly articulating pressure suit glove (that approaches nude range mobility) are greatly multiplied when the thumb is approached. The major reason for design difficulty is due to the anatomical complexity of this digitus. The physical makeup does not lend itself to assembling material for glove restraint loads when pressurized, and at the same time allow material length changes necessary for movement. An anatomical review is presented to aid in understanding the glove design complexity.

The bones of the thumb joint are the scaphoid, trapizuem, trapezoiduem, first metacarpus, and proximal and distal phalanges (Figures 2 & 3). The rotational motion of the thumb occurs because of the unique relationship of the trapezium to adjacent bones. The trapezium articulates with four bones: the scaphoid proximally, the first metacarpal distally, and the trapezoideum and second metacarpal medially. This is called the "Carpometacarpal Articulations".

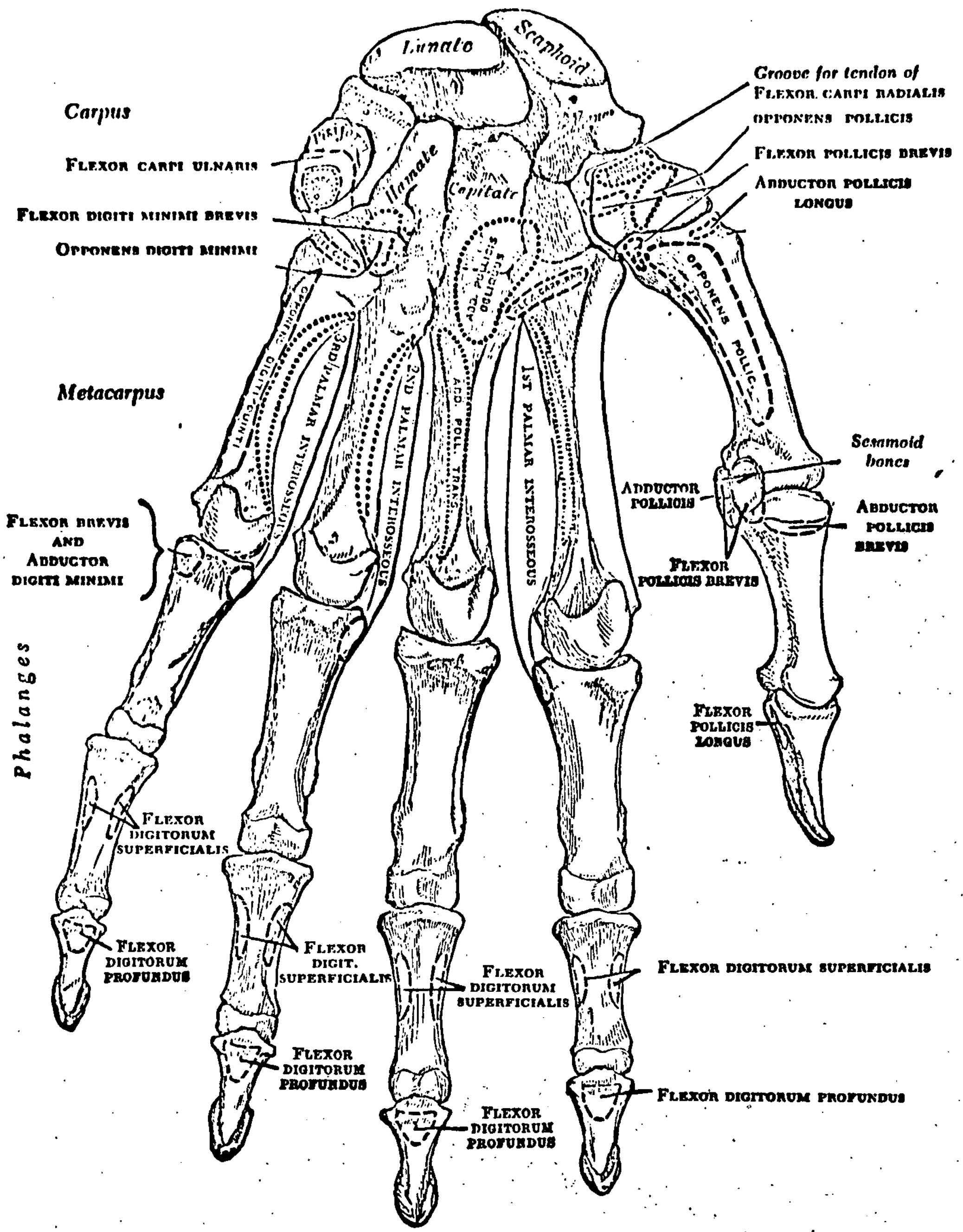
This is a joint of reciprocal reception between the first metacarpal and the trapezium; it enjoys great freedom of movement because of the configuration of its articulating surfaces, which are saddle shaped. The joint is surrounded by a capsule, which is thick but loose, and passes from the circumference of the base of the metacarpal bone to the rough edge bounding the articulate surface of the trapezium, it is thickest laterally and dorsally, and is lined by synovial membrane.

Movements - In aritculation the movements permitted are flexion and extension in the plane of the palm of the hand, abduction and adduction in a plane at right angles to the palm, circumduction, and opposition. It is by the movement of opposition that the tip of the thumb is brought into contact with the palmar surfaces of the slightly flexed fingers. This movement is effected through the medium of a small sloping facet of the anterior lip of the saddle-shaped articulating surface of the trapezium.



—Bones of the left hand. Dorsal surface.

Figure 2



—Bones of the left hand. Palmar surface.

Figure 3

Flexion is produced by the flexor pollicis longus and brevis, (Figure 4) with the adductor and opponeus acting in a somewhat synergetic fashion to hold the thumb close to the palm. Extension is effected by the extensior longus. The extensor brevis acts to produce a position midway between extension and abduction, which is the very commonly used reciprocal of opposition. Abduction is produced by the abductores longus and brevis. Adduction is carried out by the adductor with assistance from the short flexor. By the movement of opposition the metacarpal bone is rotated to a position in which the palmar surface of the thumb faces the palmar surface of the fingers. This is brought about by the opponeus, assisted by the abductors. After the thumb is in position, the strong pressure between the thumb and the fingers is produced by the long flexors.[1]

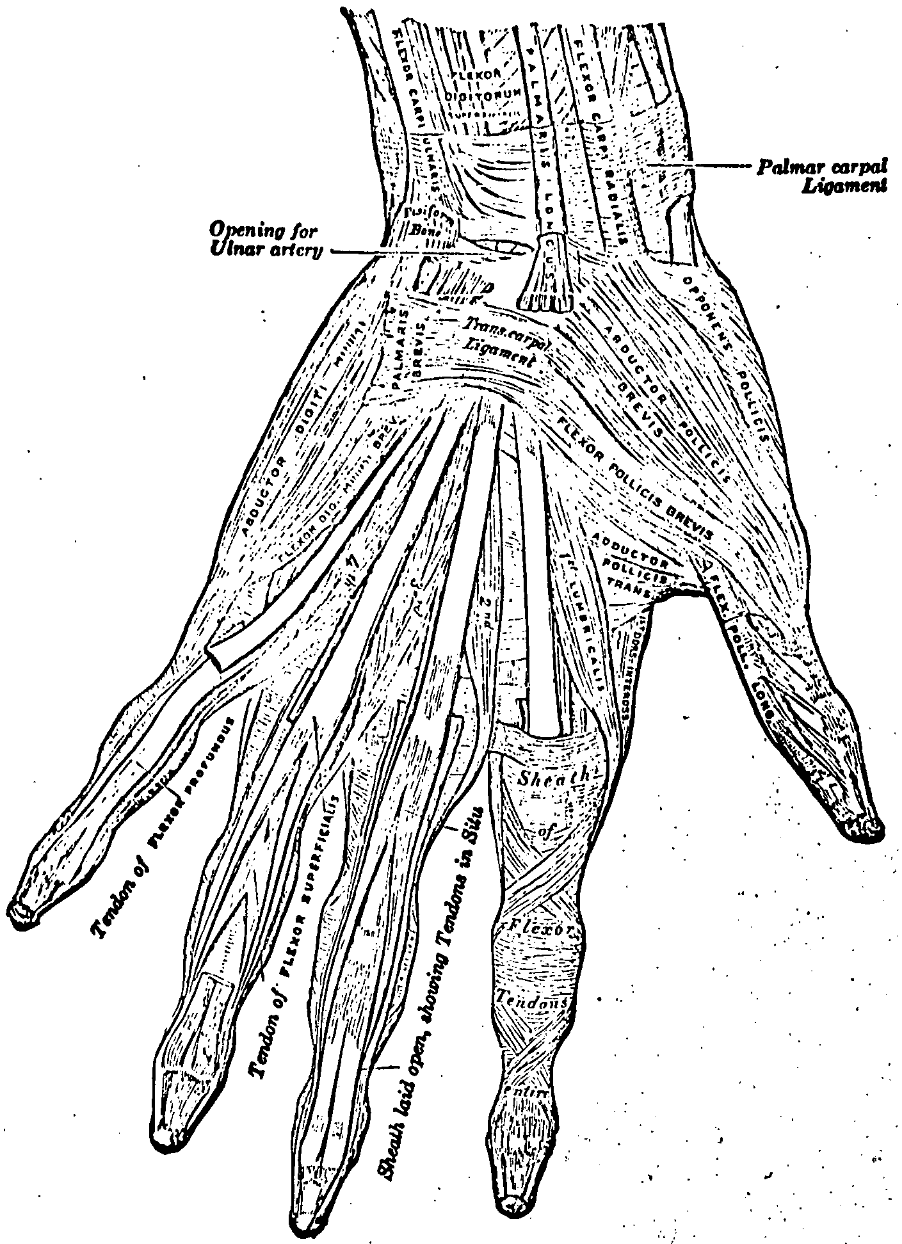
Perhaps more important than how motion is attained, is the relationship of the muscle envelope relative to the axis of motion. Figure 5 shows the first metacarpus/trapezium attachment (for this study, assumed to be the pivot axis during adduction/abduction) and the adductor pollicis transversus muscle which forms the thumb crotch. The distance from the pivot point to the crotch edge is approximately 38.10 millimeters (1.5 inches) on a medium size hand.

When we view the simple motion of adduction-abduction of a thumb relative to a pressure glove, we see an articulation point for the glove and a point for the hand (Figures 6 & 6A). Due to this pivot point, the crotch area must provide for length changes during articulation. On gloves of no internal pressure, the crotch length change can be provided by simply allowing sufficient material and this material pleats or folds during retraction. However, in a pressure glove, due to plug and hoop load pressures, the excess material tends to "balloon" resulting in excess "spring back" forces.

A review of the final report CR114365 of NASA glove program NAS2-6154, reveals the glove thumb crotch is not restrained and is allowed to balloon resulting in very high bending forces. No provisions for material control (extension/retraction) are provided for on the dorsal side of the thumb base which again resulted in a fixed configuration when pressurized.

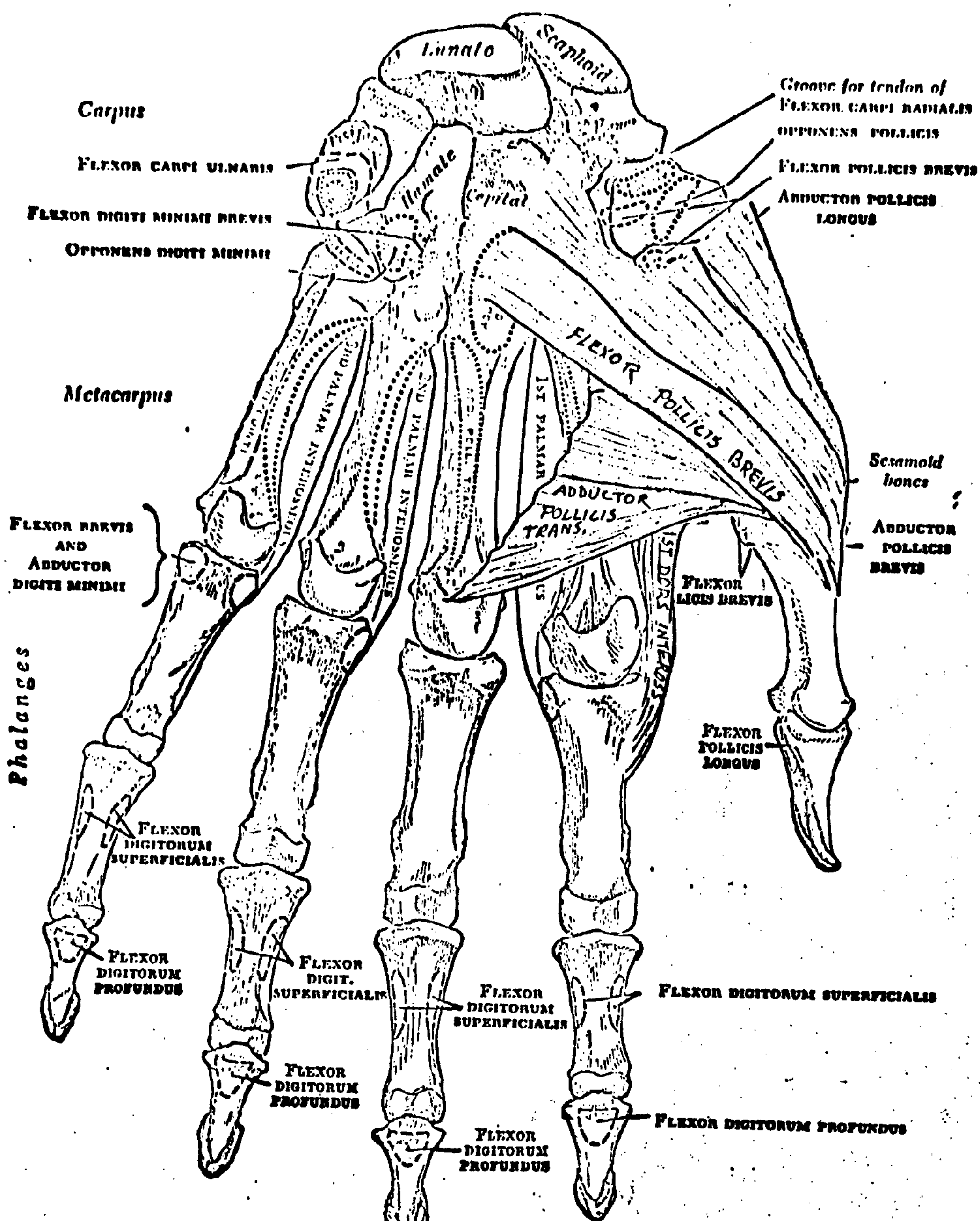
In order to better understand what is required for a functional glove thumb, a review of the various hand tasks that man normally performs was conducted. The major tasks are shown below.

[1]Gray's Anatomy, 28th Edition



—The muscles of the left hand. Palmar surface.

Figure 4



—Bones of the left hand. Palmar surface.

THUMB CROTCH AND FIRST METACARPUS/TRAPEZIUM

Figure 5

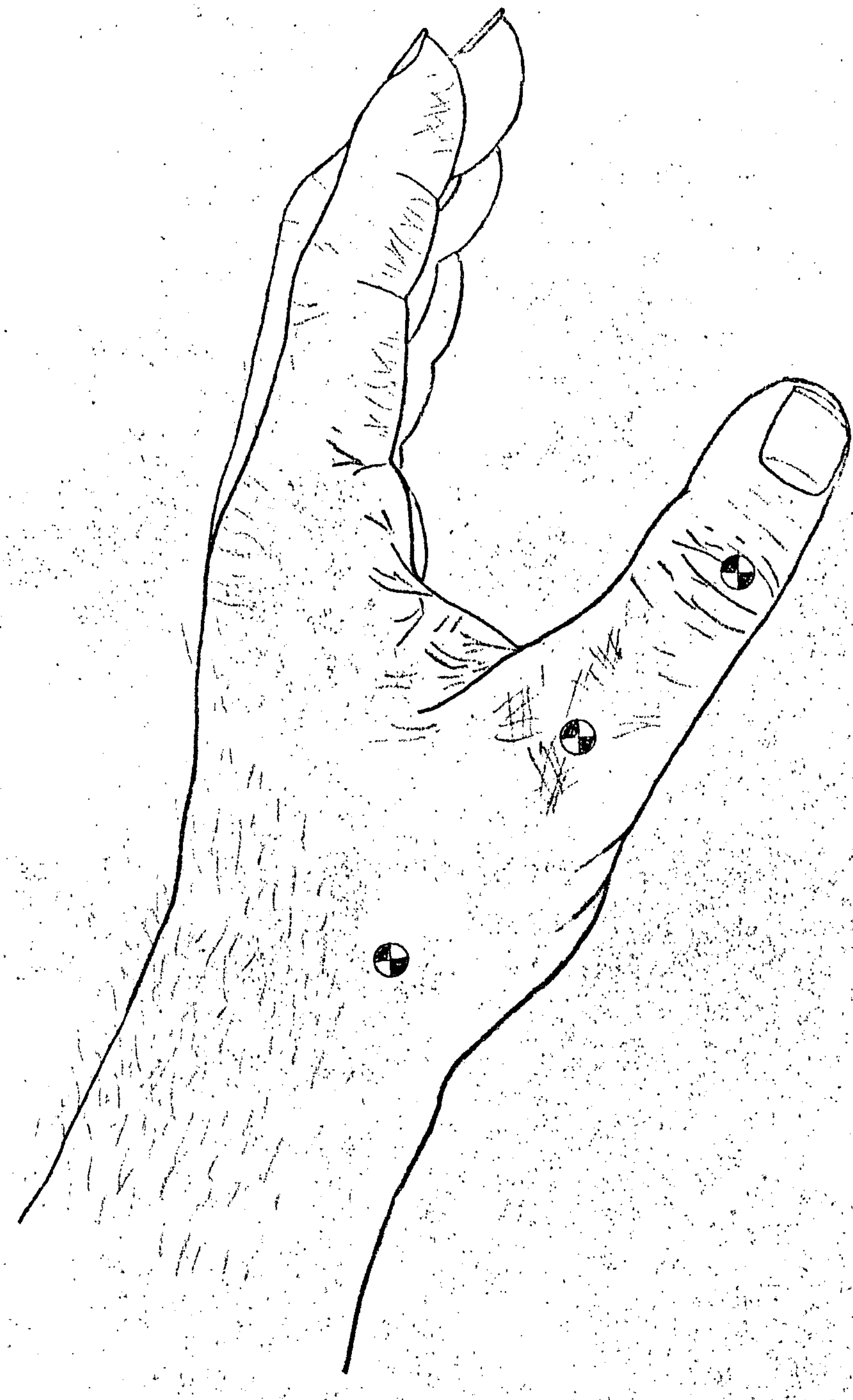


Figure 6

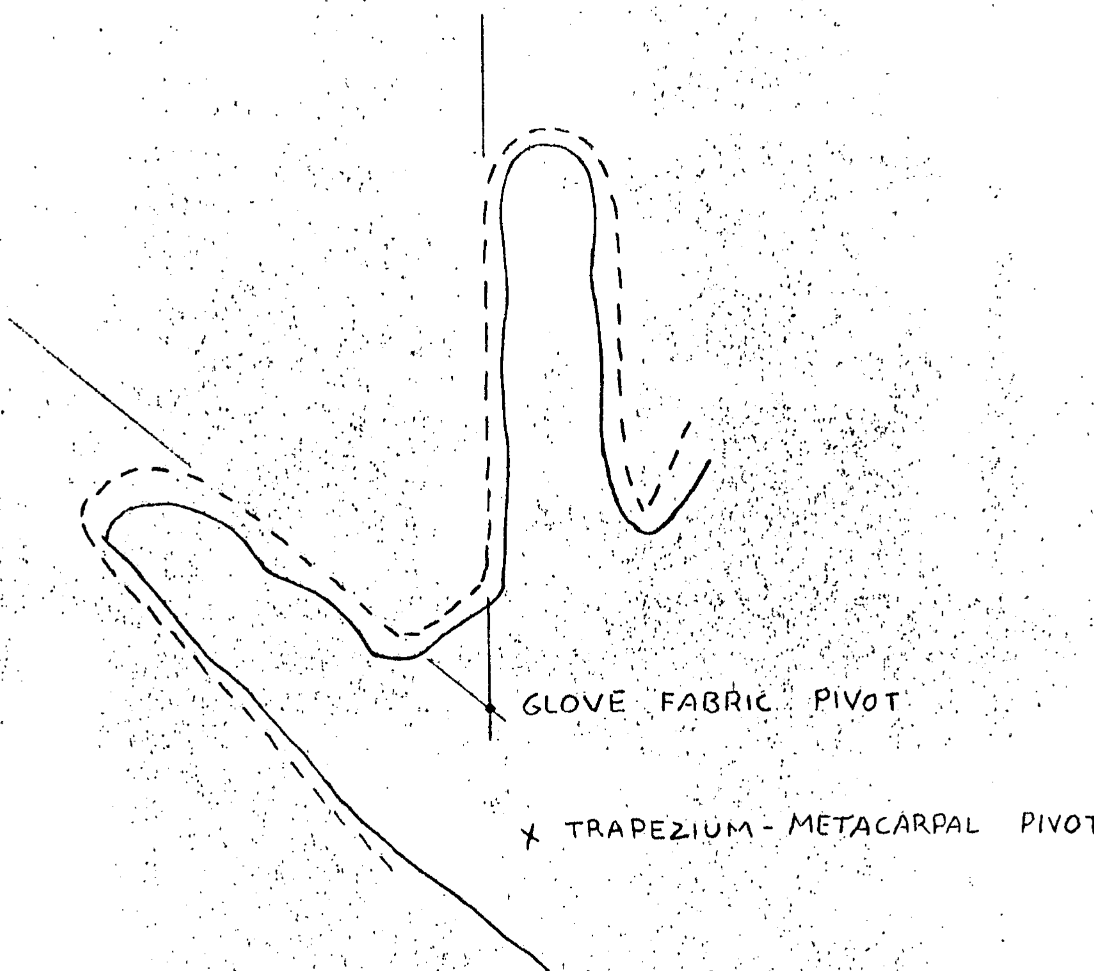
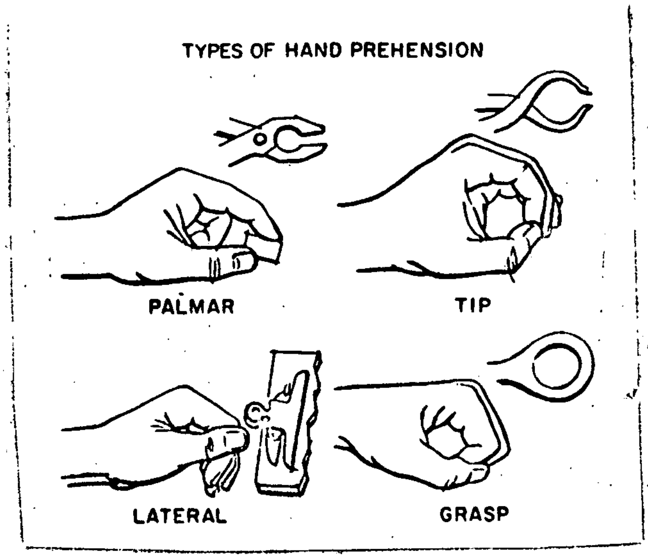


Figure 6A



An interesting fact is there is seldom a normal work task that requires a rotational thumb motion. Most of our hand tasks are confined to the grasp and palmar motion. This would indicate that our primary design requirements would be a glove design that would accomodate these primary tasks.

3.1.3 Glove Design

Our design approach was to separate the design areas of the hand (areas of different function) and generate designs that compliment the anatomical makeup and function of these areas.

For design purposes the glove was separated into the following areas:

Wrist
Palm restraint
Fingers
Thumb

3.1.3.1 Wrist - Although the wrist is capable of rotational motion, for the purpose of this design we only considered abduction-adduction, and flexion-extension. Past design concepts have used a simple cylinder or a slip cord design (including link net) for wrist motion. The cylinder is non-acceptable due to the high torque and lack of neutral range. The slip cord design is unacceptable due to high torque at the design pressure (8 psi) caused by restraint material and turnaround friction and also the problem of materials abrasion. A design that

SAC has used on successful inhouse designs consists of two single-axis joints offset 90° and separated by a rigid ring. The design is shown in Figure 7. This design concept was selected for the ptototype glove.

3.1.3.2 Palm Restraint - Three basic palm restraint designs were studied. They were:

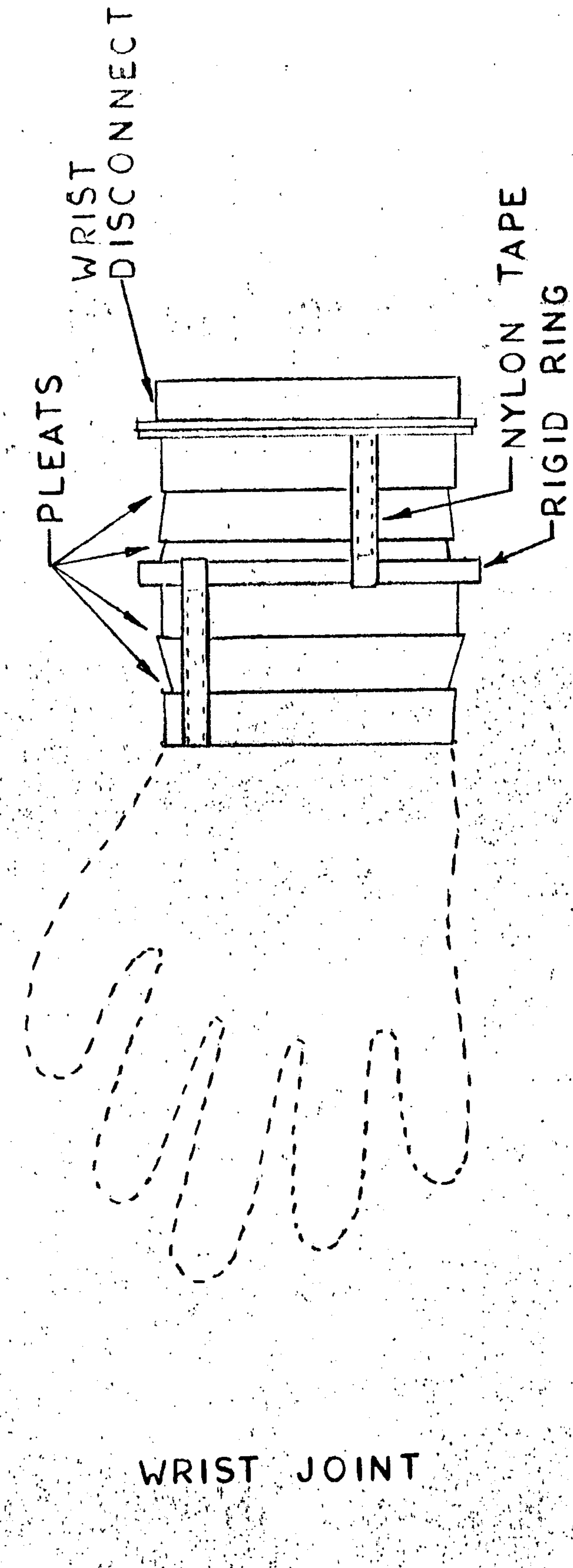
(1) Single round wire, inserted in a band sewn to the glove palm.

(2) Wire shaped in a figure T, installed in a tape sewn to the glove palm.

(3) Separate restraint that incorporates flat palm restraint, basic glove palm restraint, and finger root cords. This design interfaces with the recommended wrist joint restraint.

The following is a trade study of these restraints.

	Good	Bad
Single Wire	•Inexpensive	•Creates a severe wear point on tunnel •Allows glove ballooning •Uncomfortable •Cannot quickly change location for test
"T" Wire	•Less expensive than removable model	•Wear points on tunnels •Must be stitched to glove •Cannot quickly change •Allows glove ballooning •Severe wear points
Removable Full Palm	•Change design configuration without glove damage •Controls glove ballooning •Protects basic glove	•More expensive to manufacture than other two designs



WRIST JOINT

FIG. 7

For the prototype glove, the removable full palm restraint was selected (Figures 8 & 9).

3.1.3.3 Fingers - The following finger designs were evaluated:

(1) Mini-convolute and laminate.

(2) Reinforced dipped.

(3) Sewn fabric.

Trade studies reveal the following good and bad factors of each design.

	Good	Bad
Mini-Convolute	•Low torque	•Stiff seams along fingers •Poor flex life •Expensive to manufacture •Requires hand molds •Difficult to manufacture
Dipped	•Excellent flex life •Low torque	•Requires hand molds •Special process to manufacture
Sewn	•Low cost •Easy to manufacture •Requires no precise hand molds •Good flex life	•Requires bladder mold

Both the mini-convolute and the dipped convolute concepts were manufactured and tested. The dipped convolute consisted of dipping a hand mandrel using 16EX7A-2 neoprene solution. The reinforcement consisted of nylon marquisette applied after three dips, the glove was partially cured and a brush coat of neoprene applied and additional marquisette applied. Neoprene was added by brushing. The convolutes were dipped separately and cemented in place as shown in Figure 10. This design did not result in low torque and good motion as was anticipated. The problem was insufficient material for growth and poor control of the convolute roots which allowed excess ballooning and excess torque. We were confident that these problems could be solved by re-engineering, however, insufficient time remained to accomplish this task.

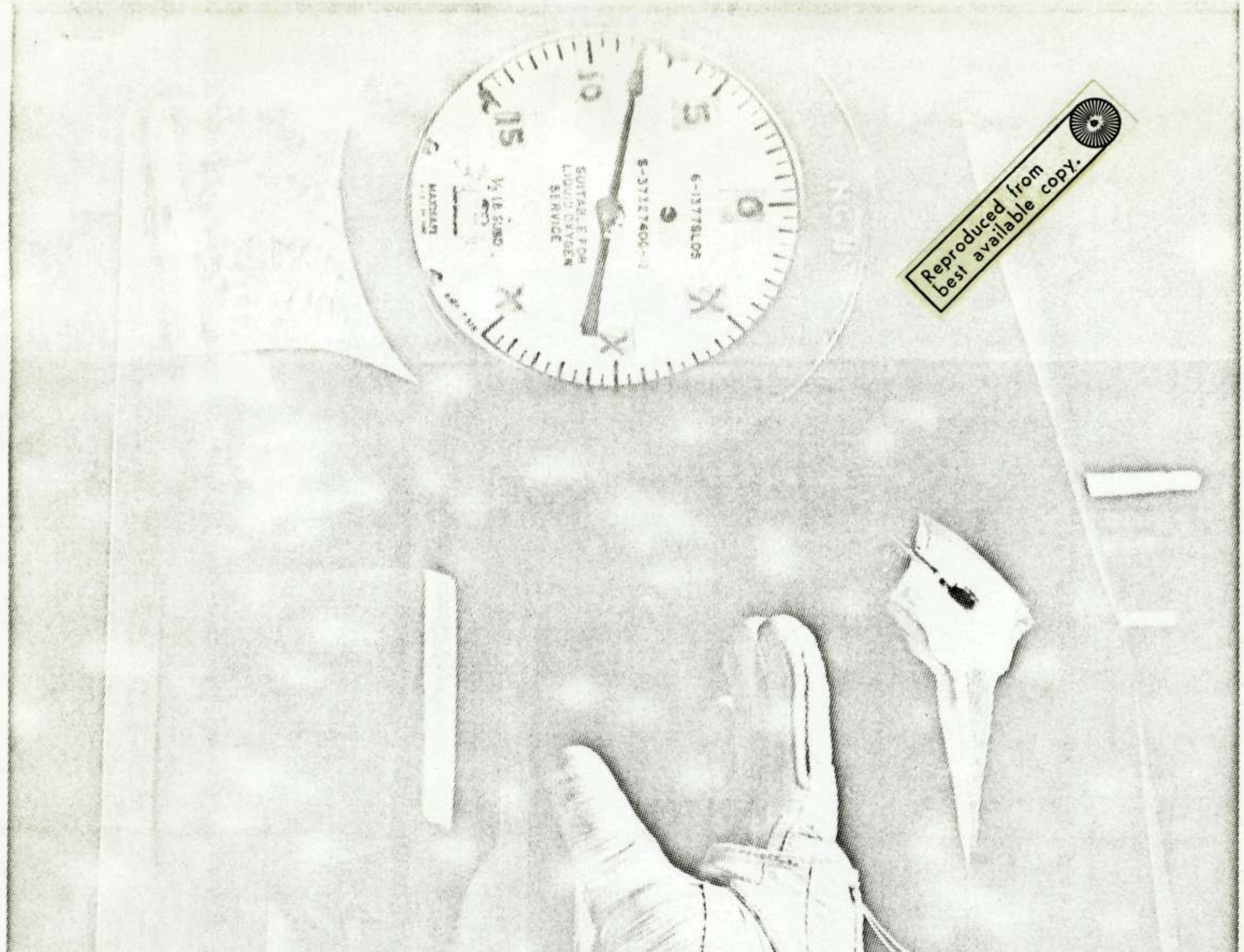


Figure 8

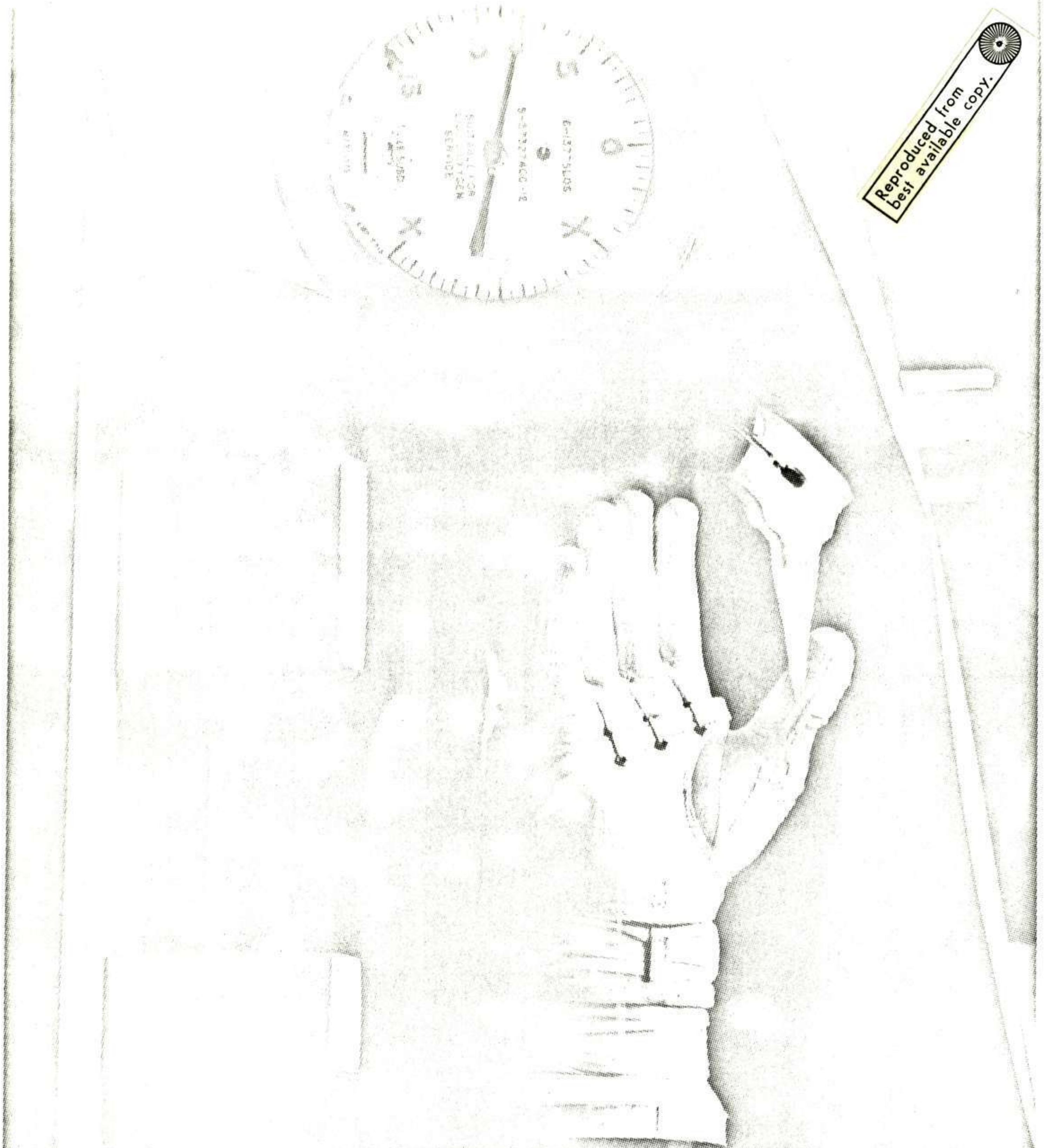


Figure 9

Figure 10

Mini-convolute joints were manufactured using standard mini-convolute material as developed under contract NAS2-6154 (Figures 11 & 11A). The convolute joints were cemented to the glove via 16EX7A-2 cement and re-enforced with two plies of nylon marquisette. Each ply was brush coated with 16EX7A-2. This resulted in a smaller seam than previous stitch and cement methods. The glove body was manufactured by dipping a hand mandrel and re-enforced with nylon marquisette as described in the dipped convolute.

3.1.3.4 Thumb - As stated in the review section, the primary thumb design problem of the previous glove program NAS2-6154, was the excess ballooning of the thumb crotch and lack of material for dorsal growth.

The basic design evolved into a convolute section that covered the dorsal surface from the trapezium to the middle of the distal phalange (see Figure 12). The crotch is sized for mid-adduction and is restrained via the palm restraint. This also serves as a breakpoint and allows material to move under the restraint fabric.

4.0 CONCLUSIONS/RECOMMENDATIONS

Significant advances were accomplished in manufacturing a pressure glove for operating at a pressure of 8 psi. Of significant importance is the method of glove assembly without excess stitching or cementing. It is recommended that further study be conducted to develop finger joints that incorporate integral convolute and glove body which would eliminate seams and provide better mobility and integrity.

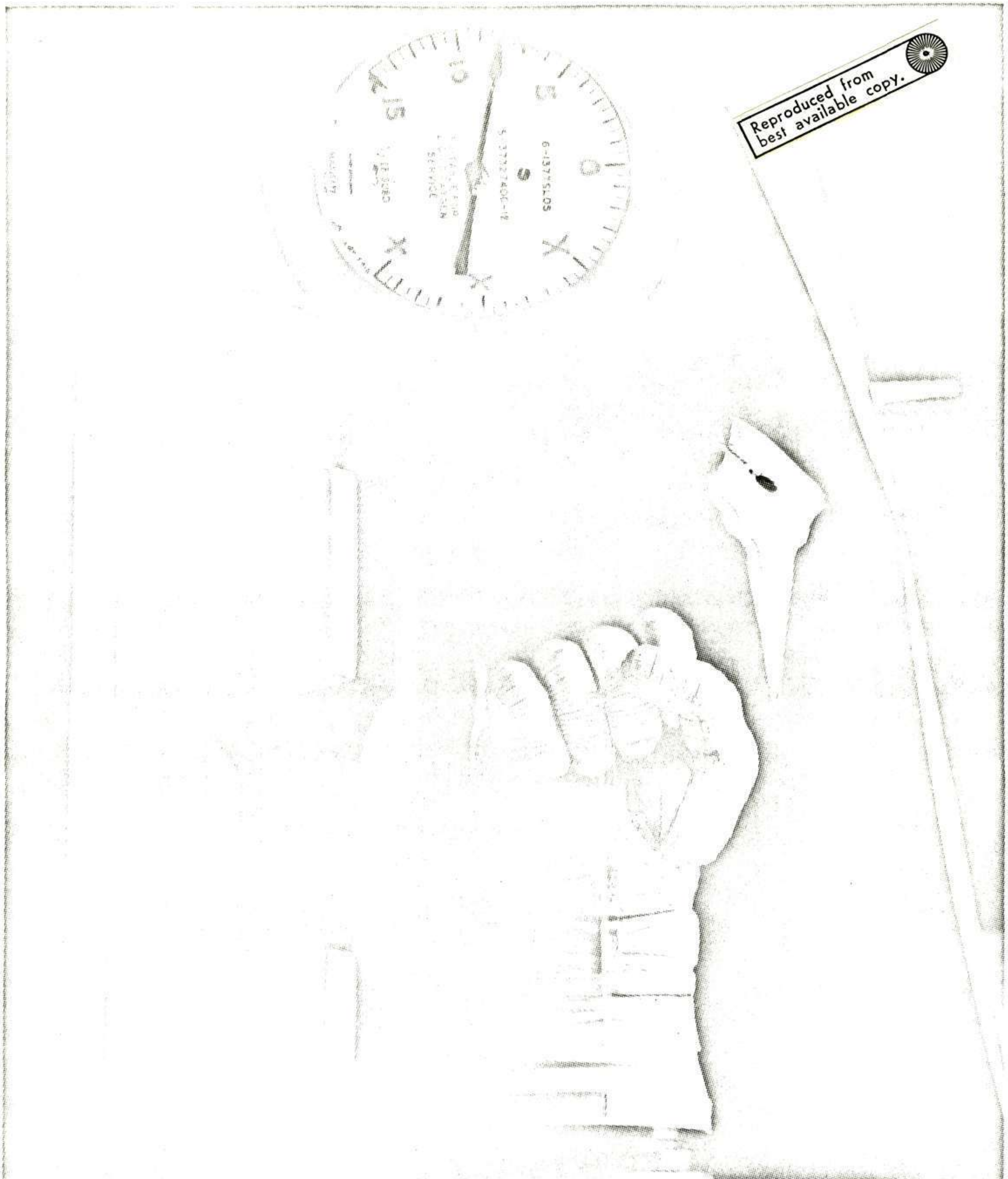


Figure 11

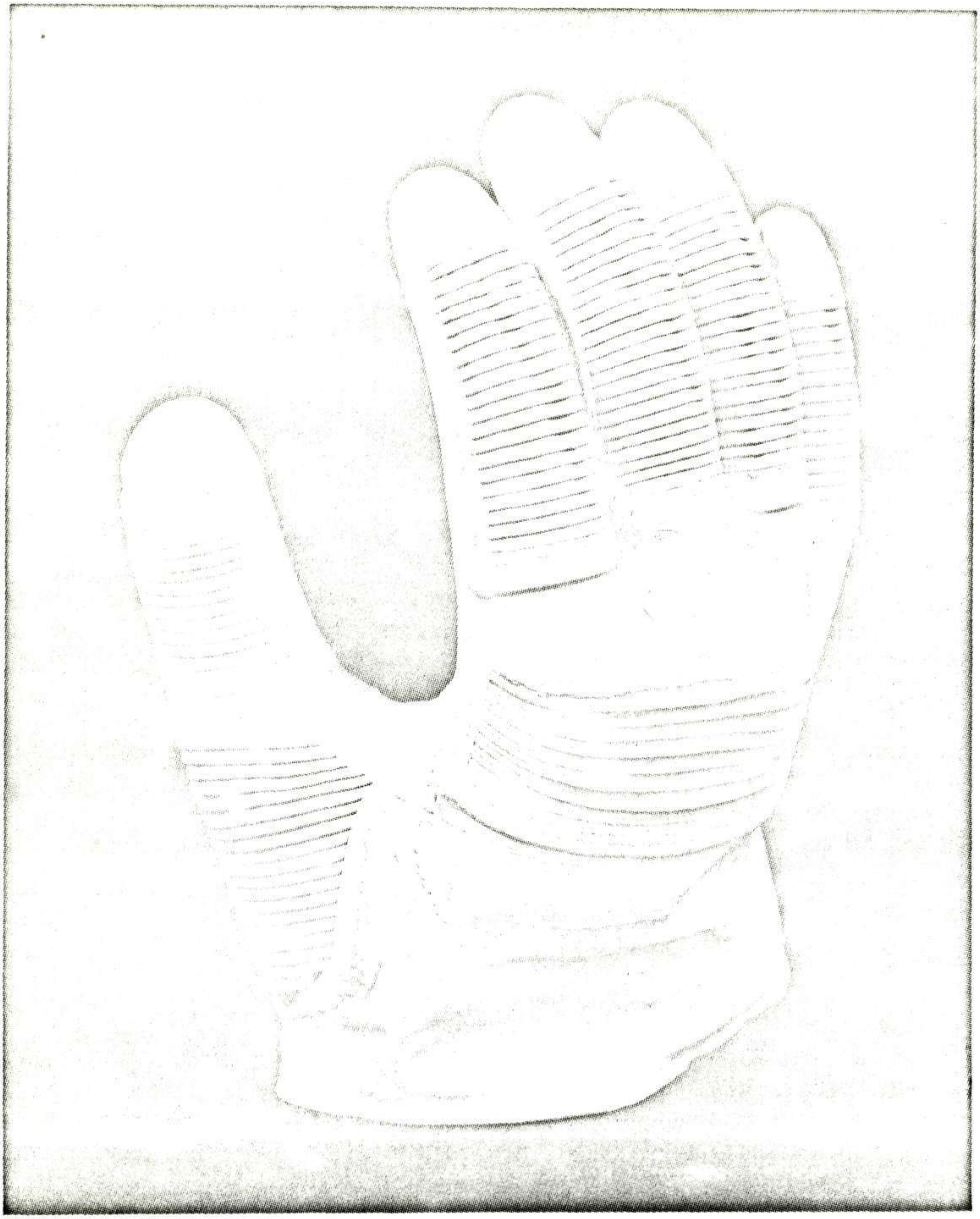


Figure 11A